Seasonal and Interannual Trends in Antarctic Ice Sheet Microwave Data

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ABSTRACT

Time-series microwave satellite observations are used to investigate seasonal and interannual changes in the surface characteristics of the Antarctic ice sheet. Enhanced-resolution C-band ERS-1/2 scatterometer (ESCAT) backscatter and DMSP SSMI brightness temperature images of Antarctica, acquired on a 3-day interval between 1992 and 1997, have been analysed. Both ESCAT and SSMI data show a clear seasonal cycle over all areas of the ice sheet. Using multi-layered radiative transfer models we demonstrate these cycles result primarily from thermal forcing. We also note significant interannual trends in both data sets. At the margins of the ice sheet, where melting is known to have occurred, backscatter and brightness temperature trends are typically less than -0.25 dB/year and greater than +1 K/year, respectively. It is likely these trends are linked to accumulation of new snow and successive burial of scatterers (formed during the last significant summer melt period). In the interior of the ice sheet, where no melting occurs, there is generally no significant trend in the backscatter and a slight negative trend in the brightness temperatures. However, there are large spatial variations which we believe is caused by the presence of depth hoar layers or higher accumulation rates.

INTRODUCTION

The Antarctic ice sheet plays an important role in the climate system, yet little is known about how it changes in response to local and global climate. Studies have demonstrated that Antarctica is experiencing change. Direct observations of changes over the past fifty years in ice-shelves on the Antarctic Peninsula show an overall retreat [1]. The extent and duration of the summer melt season on the Peninsula have been determined from satellite passive microwave data indicating summer melting increased by about one day per year between 1978-1991 [2]. Recent comparisons of Ku-band scatterometer images of Antarctica acquired in 1978 and 1996, from the ill-fated Seasat and NSCAT missions, respectively, demonstrated that significant changes have occurred during the intervening 18 years [3]. Whether such changes are a result of possible global warming, as predicted by [4], or some other naturally occurring phenomenon such as the eight-year Antarctic circumpolar wave [5] needs to be established, and this can only be achieved by long-term monitoring.

DATA

Microwave satellite remote sensing provides the only practical way of quantifying long-term changes in the properties of the Antarctic ice sheet. Data from such missions can be acquired in all weather conditions and provide detailed information on both the surface and sub-surface of the ice sheet. Data from spaceborne active microwave instruments, including scatterometer (SCAT) and synthetic aperture radar (SAR), have been routinely collected since 1991, and from passive microwave radiometers (PMRs) since 1978.

In this study we utilise C-band (5.3 GHz) VV-polarised ERS scatterometer (ESCAT) and 19 GHz, V-polarised DMSP SSMI PMR time-series image data acquired between 1992 and 1997. The scatterometer image reconstruction with filtering (SIRF) algorithm [6] was used to process ESCAT data. This technique provides three-day interval averaged backscatter (σ^0) image data at 40° (mid-swath) incidence resampled onto a 9 km polar-stereographic grid. SSMI image data are provided from NSIDC as daily averaged brightness temperature data (T_b) resampled on a 25 km grid. In addition to satellite data we have utilised NCEP/NCAR reanalysis time-series atmospheric data to provide surface temperature T_s and precipitation rate $PRATE$ information.

SEASONAL CHANGES

We have analysed time-series data from a number of glaciologically dstinct regions in Antarctica (ice shelves, ice streams and regions of low and high accumulation) and note that microwave signatures (σ^0 and T_b) from these regions all contain a seasonal and interannual signal. The Ronne Ice Shelf, NW Antarctica, provides a particularly good example of seasonal change and neutral long-term change, as illustrated in Fig. 1. In this figure, time-series σ^0, T_b, T_s and $PRATE$ data have been extracted from a $5\times1°$ box positioned over the interior of the ice shelf. A clear seasonal cycle is observed in both σ^0 and

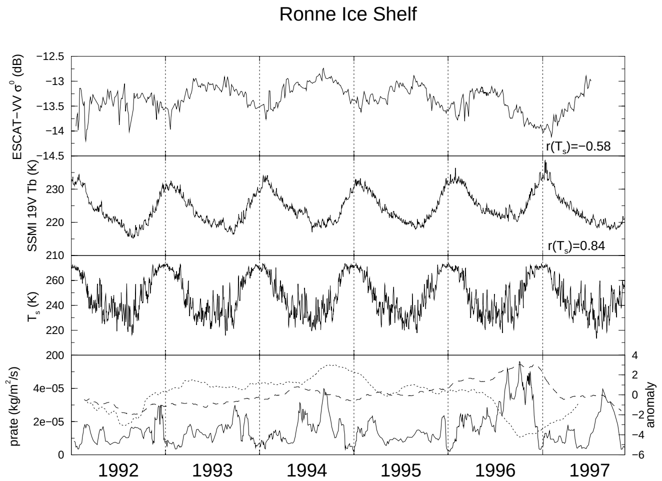

Figure 1: Time-series data for the Ronne Ice Shelf are represented as solid lines. Anomaly data (*i.e.* mean annual cycle removed) for ESCAT (units$\times$10 dB) and SSMI (K) are represented as dotted and dashed lines, respectively.

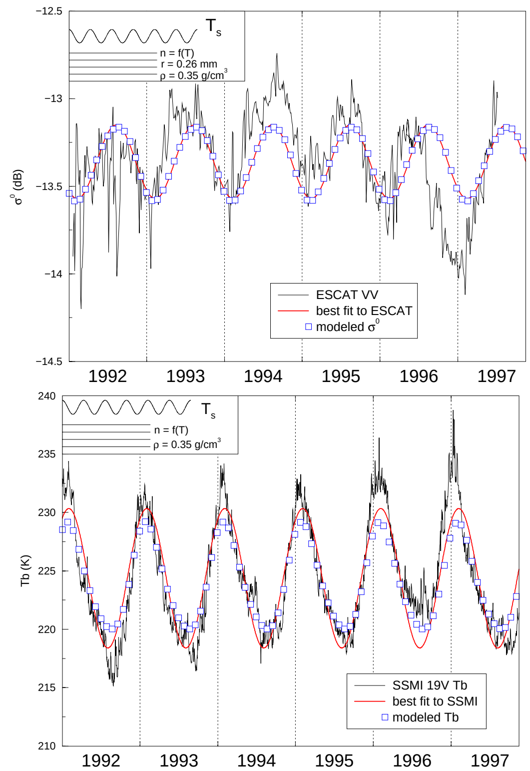

Figure 2: Comparison between observed and modelled signatures with seasonally modulated surface temperature forcing.

T_b signatures. These signatures are highly correlated with T_s (correlation coefficient is -0.58 and 0.84, respectively) implying seasonal thermal forcing is the primary contributing factor to seasonal changes observed in microwave signatures. In order to demonstrate how temperature impacts on microwave signatures we have utilised radiative transfer models for predicting σ^0 [7] and T_b [8] from multi-layered Antarctic firn. In the case of the σ^0 model, temperature alters the dielectric properties of firn and thus on the degree of electromagnetic scattering and absorption; for the T_b model temperature primarily affects microwave emission. In our computation we fit a cosine function to T_s in order to model seasonal temperature forcing and assume firn temperature decreases exponentially with depth z, by: $\exp\left(-z(w/2k)^{1/2}\right)$, where w is frequency and k is the thermal diffusivity. Modelled σ^0 and T_b signatures for typical Antarctic firn stratigraphy [9] with a mean surface crystal radius of 0.26 mm and density 0.35 g/cm^3 are compared with satellite-observed values in Fig. 2. The modelled signatures are almost identical to the mean annual microwave signatures (computed as a best-fit to the satellite data) which affirms thermal forcing is the main factor that influences seasonal variability in σ^0 and T_b by altering the scattering, absorption and emission properties of the firn layers.

INTERANNUAL CHANGES

Preliminary studies of time-series microwave image data of Antarctica have revealed clear interannual trends in addition to seasonal cycles. This is illustrated in time-series data for Palmer Land, Thwaites Region and Amery Ice Shelf (Fig. 3). All three plots indicate an interannual trend in both σ^0 and T_b signatures. Of particular significance is the Amery Ice Shelf which has experienced a decrease of over 0.5 dB/yr in σ^0 between 1992-97 and an increase of over 10 K/yr in T_b during the same period. It is likely these trends are related to annual accumulation. Evidence to support this assertion is provided in the plot of anomaly data presented in Fig. 1 which shows during periods of high accumulation σ^0 decreases and T_b increases. It is likely σ^0 decreases because fresh snow attenuates radar energy incident and scattered from underlying firn; T_b, on the other-hand, increases due to a net increase in emissivity.

The rate of change in σ^0 and T_b during the period 1992-97 for every pixel location over the entire Antarctic ice sheet is shown in Fig. 4. The images presented in this figure were constructed by computing the slope coefficient from a linear fit to the time-series data on a pixel-by-pixel basis. In general, σ^0 shows a weak negative trend over the entire ice sheet with most significant changes occurring at the margins; T_b shows a slight negative trend over the interior and large positive trends at the margins. The regions at the margins showing most significant change coincide with regions known to have experienced past melt-events [10]. It is likely, therefore, that changes are due to successive burial of scatterers formed during the last significant summer melt period (prior to 1992). Within the interior, where no melting has occurred, there are regions showing significant trends (e.g. the West Antarctic ice sheet). We believe this is due to either relatively higher accumulation rates or the burial of depth-hoar layers formed during previous years.

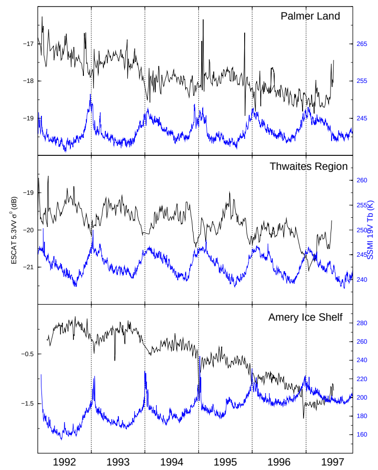

Figure 3: Time-series data for Palmer Land, Thwaites Region, and Amery Ice Shelf.

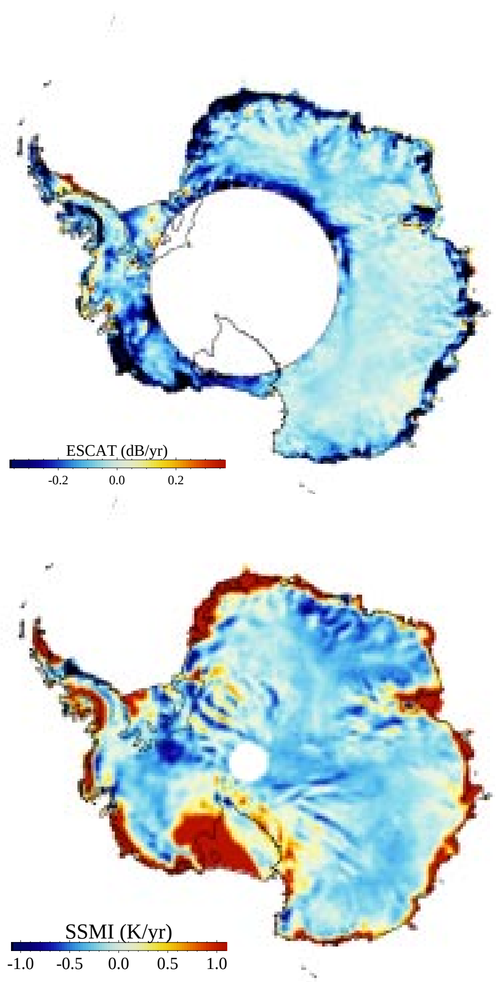

Figure 4: Rate of change of ESCAT and SSMI signatures over the Antarctic ice sheet during the period 1992-97.

CONCLUSIONS

In this paper we have studied seasonal and interannual variability in ESCAT and SSMI image data of the Antarctic ice sheet. We note clear seasonal cycles in both sets of data over all regions of the ice sheet. These cycles are attributed to seasonal surface air temperature forcing which alters the absorption and emissivity of the firn. Significant interannual trends are also noted over some interior regions of the ice sheet and, in particular, at the margins. These changes are caused by the accumulation of snow resulting in successive burial of scattering layers formed during past melt events or as depth hoar. It is possible that regions showing change are also linked to high accumulation rates or surface roughness changes and this will be the focus for future work.

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REFERENCES

1. D. Vaughan and C. Doake, “Recent atmospheric warming and retreat of ice shelves on the Antarctic Peninsula,” Nature, vol. 379, no. 6563, pp. 328–331, 1996.
2. J. Ridley, “Surface melting on Antarctic peninsula ice shelves detected by passive microwave sensors,” Geophys. Res. Letts., vol. 20, no. 23, pp. 2639–2642, 1993.
3. M. Drinkwater and D. Long, “Seasat, ERS-1/2 and NSCAT scatterometer observed-changes in the large ice sheets,” ESA, vol. SP 424, 1999.
4. J. Mercer, “West Antarctic ice sheet and CO_2 greenhouse: a threat of disaster,” Nature, vol. 271, no. 5643, pp. 321–325, 1978.
5. W. White and R. Peterson, “An Antarctic circumpolar wave in surface pressure, wind, temperature and sea-ice extent,” Nature, vol. 380, no. 6576, pp. 699–702, 1996.
6. D. Long, P. Hardin, and P. Whiting, “Resolution enhancement of spaceborne scatterometer data,” IEEE Trans. Geosci. Remote Sensing, vol. 31, no. 3, pp. 700–715, 1993.
7. A. Bingham and M. Drinkwater, “Backscatter characteristics of layered Antarctic firn,” In Preparation.
8. W. Burke, T. Schmugge, and J. Paris, “Comparison of 2.8- and 21-cm microwave radiometer observations over soils with emission model calculations,” J. Geophys. Res., vol. 84, no. C1, pp. 287–294, 1979.
9. R. Alley, J. Bolzan, and I. Whillans, “Polar firn densification and grain growth,” Ann. Glaciol., vol. 3, pp. 7–11, 1982.
10. H. Zwally and S. Fiegles, “Extent and duration of Antarctic surface melting,” J. Glaciol., vol. 40, no. 136, pp. 463–476, 1994.